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INFRARED VIDICON DEVELOPMENT

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13. ABSTRACT

The objective of this program has been to demonstrate the feasibility of using metal-silicon Schottky barrier diode arrays in the retina of an infrared vidicon. Such arrays promise to be substantially more uniform in this application than other available approaches. Since retina non-uniformities are the major factor limiting system sensitivity, improvements in uniformity would permit substantial gains in system performance. To demonstrate these improvements, it is necessary to employ a demountable camera tube with which a number of retinae of varying designs can be evaluated (keeping operating parameters such as electron optics, retina temperature, etc., constant).

Such a demountable camera tube has been built and tested, and is currently being used in ongoing studies of infrared imaging using metal-silicon Schottky barrier infrared vidicon retinae. The tube can be operated in the high beam velocity mode (either positive or negative variation), or in the low beam velocity mode.

The retina structure which was developed under this contract and which is currently under continuing study consists of an active region 34 mm in diameter of 8 μm square diodes on 10 μm centers. It shows a long wavelength cut-off of 3.65 μm, is self-reticulated, and free from blooming arising from surface inversion. Excellent resolution and lag characteristics are anticipated.

In conclusion, the demountable camera tube described herein provides an excellent experimental tool for studying infrared vidicons, especially high beam velocity mode tubes.

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Deltacon						

FOREWORD

The work described herein was the result of substantial contributions by a number of people. Those to whom special recognition are due include the following:

Name	GE Company Organization	Technical Area
A. S. Baran	Space Division	Electronics
B. L. Corrie	Integrated Circuit Center	Retina Fabrication
D. W. Dale	Space Sciences Laboratory	Electronics
J. Q. Gale	Space Sciences Laboratory	Electronics
D. W. Grantham	Space Sciences Laboratory	Mechanical Design
R. W. Redington	Corporate Research & Development	Consultation
R. F. Schwarz	Space Sciences Laboratory	Theory
H. G. Sippach	Imaging and Display Devices Operation	Consultation
J. P. Spratt	Space Sciences Laboratory	Principal Investigator
L. W. Springer	Space Sciences Laboratory	Vacuum Technology

PREVIOUS AND RELATED CONTRACTS AND PUBLICATIONS

The research work described herein is supplemented by work done under two related contracts.

Contract Number	Title
F19628-73-C-0267	Vidicon Uniformity
F19628-73-C-0306	Infrared Imager Test Facility

Some of the work described herein was reported upon in the following technical presentation.

Title	Author(s)	Meeting
Metal-Silicon Schottky Diode Arrays as Infrared Vidicon Retinae	J. P. Spratt and R. F. Schwarz	International Electron Devices Meeting, December 1973, Washington, D.C.

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A. Objective

The objective of this program has been to demonstrate the feasibility of using metal-silicon Schottky barrier diode arrays in the retina of an infrared vidicon. Such arrays promise to be substantially more uniform in this application than other available approaches. Since retina non-uniformities are the major factor limiting system sensitivity, improvements in uniformity would permit substantial gains in system performance. To demonstrate these improvements, it is necessary to employ a demountable camera tube with which a number of retinae of varying designs can be evaluated (keeping operating parameters such as electron optics, retina temperature, etc., constant). The design, fabrication and characterization of such a demountable camera tube occupied the major part of the effort expended under this program. A detailed discussion of this effort is given below.

B. Design of Demountable Camera Tube

1. General Features of Tube

In order to describe clearly the many features which must be designed into an infrared vidicon, it is helpful to consider first the mode of operation of a basic element of the retina, viz. a metal-silicon Schottky barrier diode operating in the photon flux integrating mode (or storage mode).[1]

a. Storage Mode Operation of Photodiodes

The charge-storage operation of a photodiode is illustrated in Figure 1. A photodiode can be represented by a junction capacitance, a diode reverse leakage current, and a photocurrent if radiation is present. When an electron beam periodically contacts a diode element in the array, the junction capacitance is charged to the applied voltage. During the frame time, when the beam is disconnected from that diode element, the voltage across the capacitance discharges through the photocurrent by an amount proportional to the optical image intensity, if the reverse leakage current is much smaller than the photocurrent. Then, the recharging of the diode by the beam, after the frame period, creates the video signal that is proportional to the intensity of the radiation.

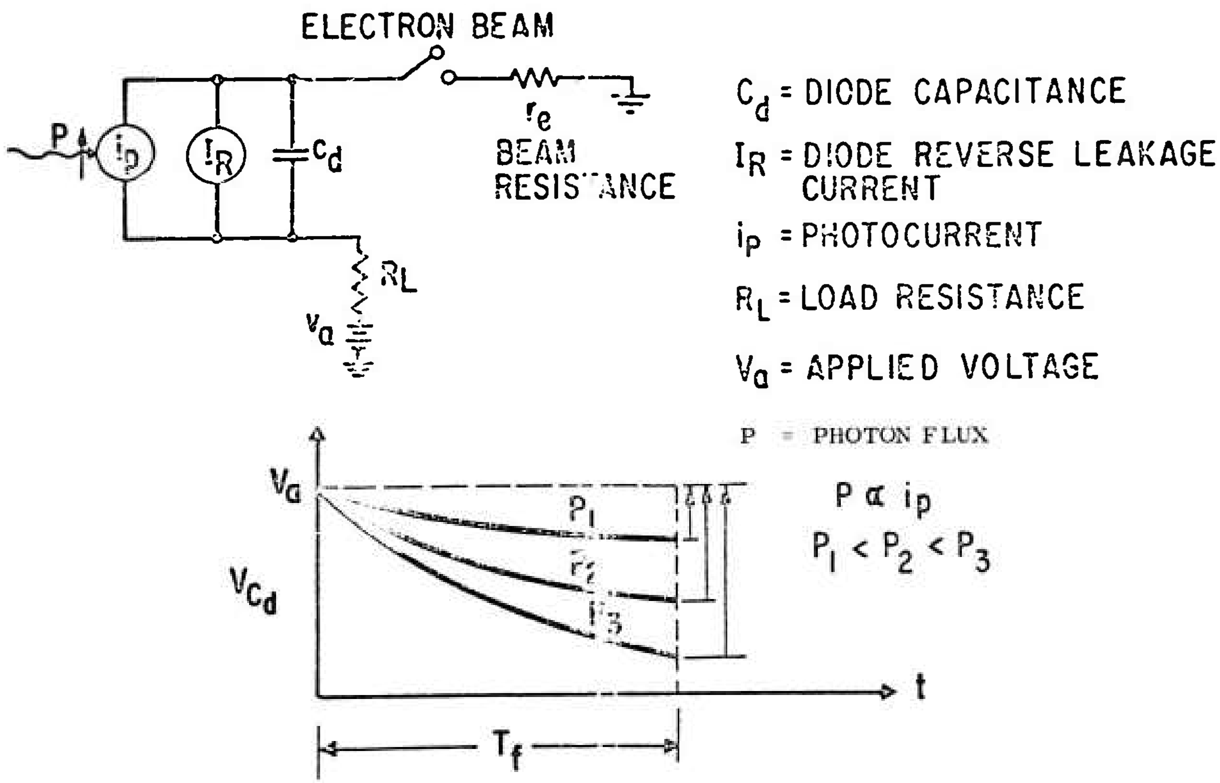


Figure 1. Illustration of Charge Storage Operation of a Photodiode

Thus, the video signal current is increased and is much larger than the photocurrent, i_p. That is,

$$\text{Signal current} = i_p \times t_F / t_s$$

where t_F and t_s are frame and sampling times, respectively. If the sampling time is 1 μsec, the gain is about 3×10^4 with $t_F = 1/30$ second. Therefore, the charge-storage operation gives the frame time an integration gain to obtain large detectable signals. Furthermore, for low-light-level imaging, since the signal increases linearly with t_F but the noise increases as a square root of t_F, it is advantageous to use the longest integration time, as long as the dark leakage current is smaller than the photocurrent. For successful operation, therefore, the diode reverse leakage current must be low enough so that there is a negligible amount of charge leakage during the frame period when no radiation impinges on the target.

b. Infrared Photoresponse of Metal-Silicon Schottky Barrier Photodiodes

Internal photoemission in metal-silicon Schottky barrier diode structures has long been known to permit the detection of infrared radiation of wavelengths longer than the fundamental absorption edge in silicon. This process, while generally analogous to photoemission into vacuum, has certain features which are unique and have no direct counterpart in the older technology, e.g. photoemission of holes as well as electrons. The former is interesting because it permits the attainment of low barriers (therefore long cut-off wavelengths) with high work function photocathodes, such as the precious metals (Au, Ag, Pt, Pd). The quantum efficiency of internal photoemission is low, as shown by the modified Fowler relationship.(2)

$$Q.E. = C A \frac{(h\nu - \Phi_o)^2}{h\nu}$$

where Q.E. = quantum efficiency

C = constant $\approx 0.1/\text{e.v.}$

A = optical absorptance

Φ_o = barrier height $= 1.24\ \text{e.v.}/\lambda_o\ (\mu\text{m})$

λ_o = long wavelength cut-off of diode .

Using the value for barrier height obtained in the Pd-Si system (Φ_o = 0.34 e.v.) one obtains a Q.E. ≈ 0.1% at a wavelength of 2.7 μm. While this value is low compared to that attainable with photoconductive or photovoltaic detectors, the ability to fabricate these devices in large arrays recommends their use for electron beam scanned infrared vidicon retinae ($\lambda > 1$ μm), where storage mode operation permits one to overcome to some extent the disadvantages of low efficiency.

One problem which must be kept in mind in connection with the use of Schottky diodes for infrared vidicon retinae is the relationship between long wavelength cut-off and operating temperature. Thermally generated leakage must not discharge the back bias placed across the diode in a time less than the frame time. Thus

$$\frac{I_{th} t_F}{C} \leq V_R$$

where I_{th} = thermal leakage across the diode

t_F = frame time = 1/30 second

C = junction capacitance

V_R = maximum reverse bias across diode .

The thermal leakage across the diode is given by

$$I_{th} = A^* T^2 \exp - q\Phi_o/kT \quad .$$

Also,

$$C = \frac{\kappa \epsilon_o}{d}$$

where A^* = modified Richardson constant $\qquad \kappa$ = relative permittivity

Φ_o = barrier height (e.v.) = $1.24/\lambda$ (μm)

d = depletion layer width .

Substituting, we get

$$t_F \leq \frac{\kappa \epsilon_o E_{max}}{A^* T^2} \exp \frac{q}{kT} \frac{1.24}{\lambda_o (\mu m)}$$

where $E_{max} = V_R/d$.

If we assume that the maximum field strength which the junction can sustain is limited by avalanche breakdown, then E_{max} will be in the range of 3 to 4 x 10^5 V/cm for doping levels of interest, and is nearly independent of temperature.[3] Thus, the required operating temperature can be plotted vs. λ_o. Figure 2 is a plot of the above relationship where y_1 is given by

$$y_1 = \frac{1.44\,^oK\text{-}\mu m}{\lambda_o\ (\mu m)}$$

while y_2 is given by

$$y_2 = T\,\ell n\left(\frac{T}{T_o}\right)^2$$

$$T_o = \left[\frac{\kappa\,\epsilon_o\,E_{max}}{t_F\,A^*}\right]^{1/2} = 5.65 \times 10^{-4}\ {}^oK \quad \left(\begin{array}{l}\text{for } E_{max} = 4 \times 10^5 \\ \text{and } t_F = 1/30 \text{ second}\end{array}\right).$$

To determine the maximum operating temperature T_{max} for a given cut-off wavelength, λ_o, determine y_1. Then, T_{max} is determined as the temperature for which $y_2 = y_1(\lambda_o)$. The dashed lines on Figure 2 show that for $\lambda_o = 3.5\ \mu m$, $T_{max} = 160^oK$.

This value of T_{max} is the value which would apply if retina recharging were not a limit (as, for example, in self-scanned arrays). Electron beam scanned arrays, however, are often limited in the amount of beam current available to recharge the retina. Under these conditions, the leakage current is limited by

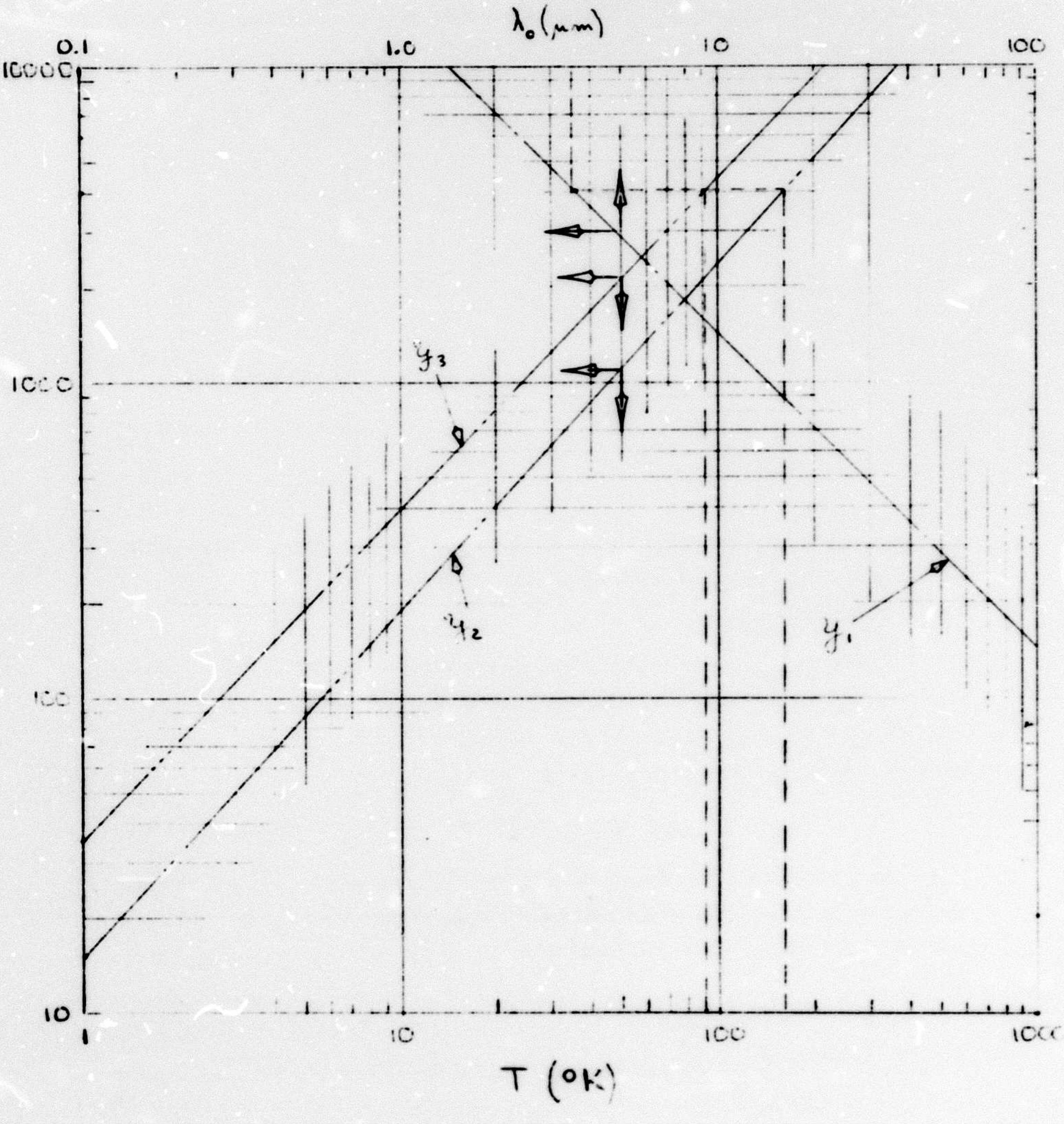
$$I_{th}\,t_F \leq I_R\,t_R\ , \qquad \text{where } I_R = \text{recharge (beam) current and } t_R = \text{read time,}$$

which states that the charge leaked off the detector in a frame time must be less than the charge that can be re-deposited in a read time. Since the read time, t_R, is of the order of $1/(2\pi$ B.W.), where B.W. = video bandwidth,

$$t_R = \frac{1}{(2\pi)(4.5\ \text{MHz})} = 3.54 \times 10^{-8}\ \text{sec}$$

and since the recharge current achievable in typical camera tubes is ≈ 20 na/cm^2, then a more stringent limitation on I_{th} results; i.e.,

FIGURE 2
NOMOGRAM FOR DETERMINING T_{MAX} FOR A GIVEN λ_0



$$I_{th} \leq \frac{t_R}{t_F} I_R \quad .$$

Using the previous relationship between I_{th} and long wavelength cut-off, we have the following relationship;

$$y_1 \geq y_3$$

where $y_1 = \dfrac{1.44\,^{o}K\text{-}\mu m}{\lambda_o\,(\mu m)}$

$$y_3 = T \ln\left(\frac{T}{T_1}\right)^2 \quad ; \quad T_1^2 = \frac{I_R\, t_R}{A^*\, t_F} = 7 \times 10^{-16}\ ^{o}K^2$$

$$T_1 = 2.65 \times 10^{-8}\ ^{o}K \quad .$$

From the curve of y_3 vs. T in Figure 2, it can be seen that, as a result of beam current limitations, the maximum operating temperature of a 3.5 μm infrared vidicon retina is 92^{o}K.

If one is willing to give up resolution, it is possible to defocus the electron beam, resulting in a large value of t_R for a given t_F. This will increase the permissible operating temperature. To compare operating temperature of self-scanned arrays with beam scanned on a realistic basis, they must be compared for similar resolution.

c. <u>High Beam Velocity Operation of Vidicon Camera Tubes</u>

In order to achieve the desired long wavelength cut-off in the infrared vidicon retina, a metal-silicon system must be chosen which has a low value of barrier height, Φ_o. This is most easily achieved using high work function metals (such as Pd_2Si) on P-type silicon. Such a choice results in a diode polarity opposite to that normally used in semiconductor diode retinae.

Conventional camera tubes use electron beams which land at a few volts potential to charge individual picture elements to the negative potential at which the cathode of the electron gun sits. Because of the polarity of the diodes used in these retinae, it is necessary to use an electron beam landing at an energy sufficiently high to dislodge secondary electrons

with a yield $\delta > 1$, thereby charging individual picture elements positively.[4] Figure 3 shows a schematic of a high beam velocity camera tube. The collector mesh is a high transparency screen used to accelerate the electron beam and to collect secondaries from the target surface (the Pd_2Si array). The combined action of the beam current, I_B, and the secondary emission current going to the mesh, I_M, will charge the floating target surface to a potential V_{FT}. Assuming that the secondary electrons are Maxwellian, one obtains[5] the following equations;

$$I_M = \int_{V_{FT}}^{\infty} \frac{di_s}{dV_z} dV_z = i_s \exp(-V_{FT}/\overline{V})$$

$$= \delta I_B \exp(-V_{FT}/\overline{V})$$

where $\overline{V}$ is the average energy of secondaries and i_s is the secondary emission current from the floating target. The net target current is

$$I_T = I_B - I_M = I_B [1 - \delta \exp(-V_{FT}/\overline{V})] \; ; \; V_{FT} \geq 0$$

$$I_T = I_B (1 - \delta) \qquad ; \; V_{FT} \leq 0 \; .$$

Neglecting leakage, the floating target will charge to V_{FT} such that $I_T = 0$; i.e.,

$$V_{FT} = \overline{V} \ln \delta \; .$$

If the electron beam is scanned across the retina in raster fashion, it will charge the floating target to this potential. Optically induced leakage will discharge the target surface down toward mesh potential during the frame time, so that a signal will be generated between retina and mesh when the beam returns to this spot during the next scan.

d. Tube Design

This very sketchy discussion of a high beam velocity infrared vidicon camera tube permits one to describe in general terms the features which a demountable camera tube must incorporate to evaluate the feasibility of this approach. Figure 4 depicts such a demountable camera tube, the details of which are described in greater detail below.

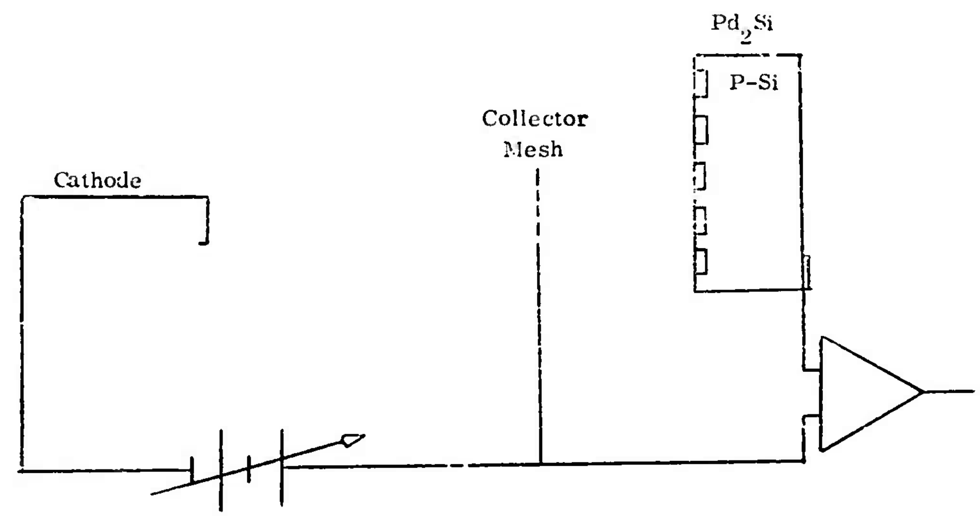


Figure 3. Schematic Diagram of High Beam Velocity Camera Tube

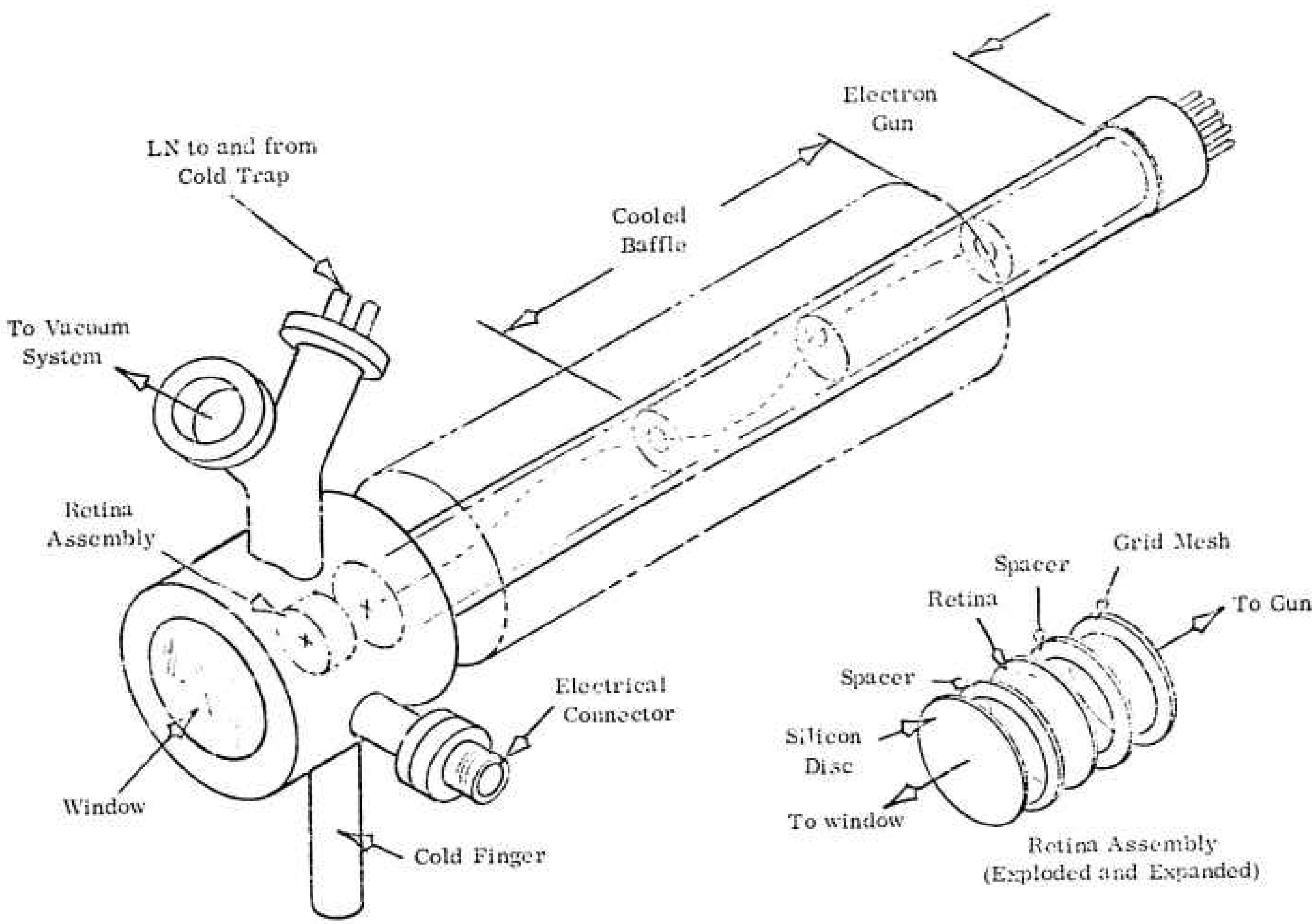


Figure 4. Demountable Camera Tube

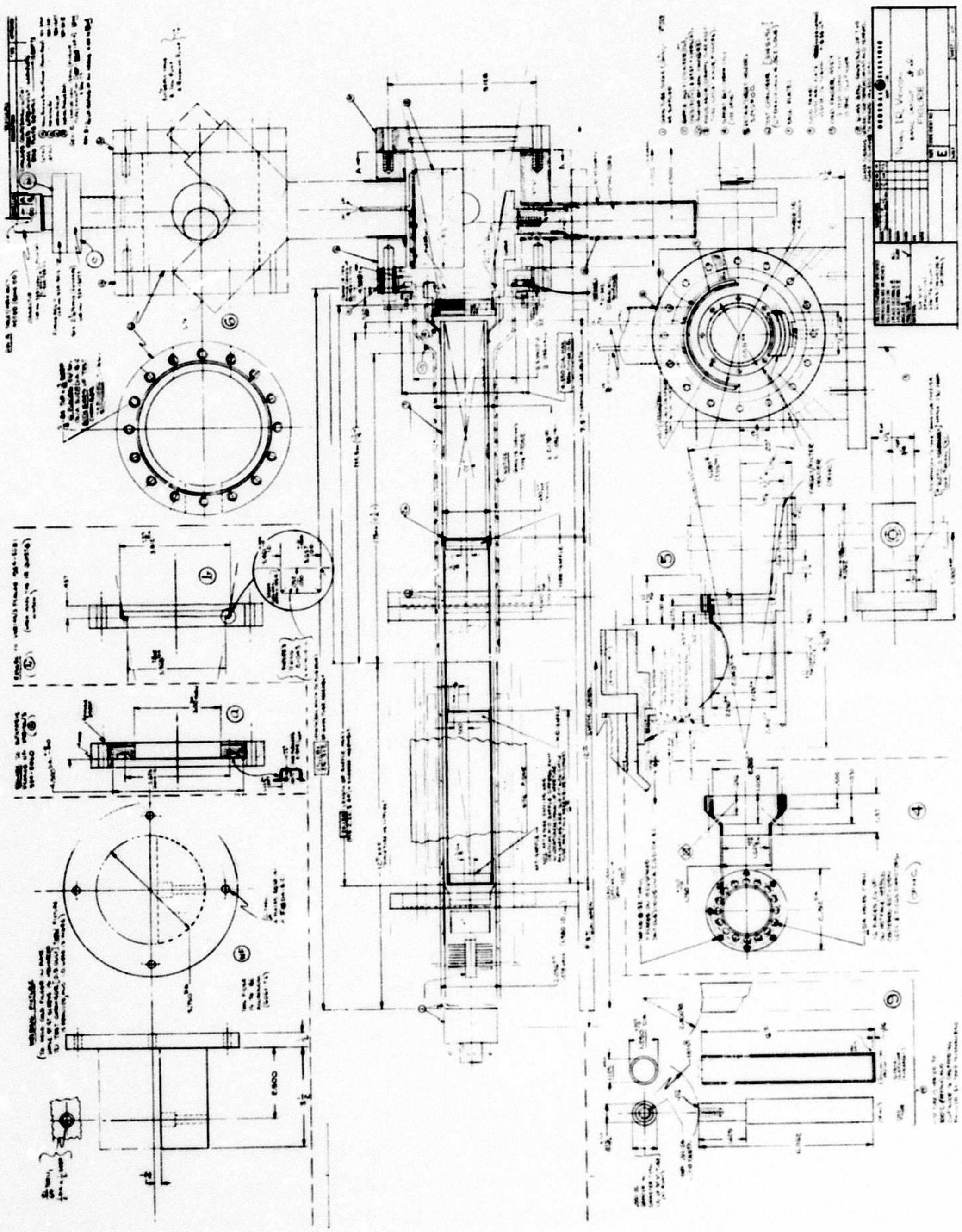
2. Vacuum System

One of the major problems encountered in operating a demountable camera tube is that of establishing and maintaining good emission from the thermionic cathode used in the electron gun. The approach used in this program was to use standard electron guns of the type employed in the GE Z7966 3-inch image orthicon camera tube. Such tubes were obtained from the factory, with the image section removed, before the cathode was activated. The problem then became one of activating the cathode in situ, and protecting the cathode after activation by good vacuum technique. Cathode activation is discussed in section 7 below. The more important features of the vacuum system are described here.

The vacuum system employs a Welch 2-stage Duo-Seal mechanical pump of 25 L/M capacity, with a cold trap to reduce oil contamination of the camera tube. The high vacuum pump used is a Hughes 30 L/sec ion pump, which is sufficiently fast to handle the 3-liter volume of the tube adequately. (Pressures in the neighborhood of 3×10^{-7} Torr are readily obtained.) After roughing the system, and before turning on the ion pump, the glass part of the system is baked overnight with heating tapes to drive off adsorbed water. Then the cathode barrel is heated using an R.F. induction heater. Power is slowly increased until the barrel glows dull red, then it is reduced sufficiently to eliminate the incandescence and allowed to bake for 1 hour. The tube is then cooled and the ion pump is turned on. After operating pressure is achieved, the retina is cooled to cryogenic temperautes, and substantial cryo-pumping occurs, indicating that water is the dominant residual left in the system. To prevent condensation on the retina, a 120 cm^2 Meissner trap is pre-cooled. Using this large surface to cryo-pump, system pressure can quickly be reduced from 3×10^{-7} Torr to 3×10^{-8} Torr.

3. Thermal Design

Figure 2 above illustrates the close relationship that exists in infrared vidicon retinae between retina temperature and tube operation. The design adopted for cooling the retina in the demountable system is shown in Figure 5. It consists of a copper cold finger, 7/8" in diameter, pressed into stainless steel (S.S.) tubing, with a 0.001" interference fit. The stainless steel tubing is welded to the S.S. camera housing to form the vacuum seal, and the interference fit between Cu and S.S. forms the thermal path to a cryogen reservoir outside of vacuum. The retina assembly holder is a large copper piece which is bolted to the cold



finger. The baffle, which shields the retina from the hot cathode, is cooled thru the retina assembly holder. A first order analysis showed that the most important parts of the thermal design were the fit between the Cu cold finger and the S.S. tube, the joint between the cold finger and the retina assembly holder, the joint between the retina assembly holder and the baffle, and the radiative load on the baffle. The important features of these are described below.

a. Interference Fit Between Cold Finger and Stainless Steel Tube

As stated above, this fit is a 0.001" interference fit; i.e., the average outside diameter of the Cu at room temperature (1.126") is 0.001" larger than the average inside diameter of the S.S. (1.125"). When fabricating the tube, the S.S. is heated to ~ $200^{\circ}C$, while the Cu is cooled to $77^{\circ}K$. The two are then joined, resulting in the desired joint after the temperature equilibrates. When the combination is then cooled to $77^{\circ}K$, the new interference can be calculated knowing the thermal coefficients of expansion (TCE) of Cu and S.S.[6] Using the average values of TCE between $77^{\circ}K$ and $293^{\circ}K$, it is found that the change of diameter of both pieces is essentially the same (.002") so that the interference stays the same on cooling.

b. Joint Between Cold Finger and Retina Assembly Holder

To assure low thermal impedance in this joint, which must be demounted every time a target is changed, special care was taken to assure intimate contact. Both the cold finger and the retina assembly holder were machined to the same radius (1.875"), and surface finished to 16 microinches R.M.S. The two pieces are held in intimate contact by a socket head S.S. screw, run up very tight.

To estimate the contribution to be expected from this joint, let us assume that the thermal path from the cold finger to the retina holder has a cross sectional area equal to that of this joint ($3.54\ cm^2$), a thermal conductivity equal to that of copper (5 watts/cm-$^{\circ}K$),[6] and that the temperature gradient desired is $0.33^{\circ}K/cm$. (This would correspond to a temperature of ~ $82^{\circ}K$ at periphery of retina.) The heat flow required to sustain this gradient is

$$Q = K A \frac{dT}{dx} = 6.0 \text{ watts} .$$

If we do not have good contact over the whole area ($A_{eff} < A_{total}$), then dT/dx locally must

increase to maintain a given Q. As a worst case, if we assume that $A_{eff}/A_{total} = 1 \times 10^{-4}$, and if the spacing between the two elements at the joint is 2.5×10^{-3} cm, then the temperature drop resulting from this spacing is only $\sim 10^{-3}$ ^oK. Consequently, we expect not to be limited by this joint.

c. Joint Between Retina Assembly Holder and Baffle

The cooling supplied to the baffle from the retina holder need only be enough to offset the radiant energy supplied to the baffle at the electron gun end by the hot cathode. To prevent excessive heat loading by the baffle on the retina holder (and also to permit bias voltage to be applied to the baffle relative to the system ground), this joint has been designed to present a high thermal (and electrical) impedance, and at the same time to provide mechanical support for the baffle assembly.

d. Radiative Heat Load on the Baffle

The baffle will absorb radiation from the hot cathode at one end, and from the tube envelope along its length. An examination of the power radiated from the glass tube (emissivity assumed to be $e_2 = 0.9$, temperature assumed to be $T = 27^oC$) to the baffle (emissivity e_1, temperature assumed to be sufficiently low that negligible power is radiated back to the glass) shows that

$$W = \sigma A_2 T^4 \frac{e_1 e_2}{e_2 + \frac{A_1}{A_2}(1 - e_2) e_1}$$

where σ = Stefan's constant
A_1 = area of cold surface
A_2 = area of warm surface

The baffle can be divided into four (4) sections, viz. section 1 thru 4, which have the following parameters.

Table I

Section #	e_1	e_2	A_1	A_1/A_2
1 (Cu)	0.6	0.9	1.4×10^2 cm^2	1.16
2 (Cu)	0.6	0.9	1.4×10^2 cm^2	1.33
3 (Al_2O_3)	0.4	0.9	2.02×10^2 cm^2	1.33
4 (Cu)	0.6	0.9	8.4×10^1 cm^2	1.18

Rewriting the equation for W

$$W = 4.6 \times 10^{-2} \frac{\text{watts}}{\text{cm}^2} \frac{1}{\frac{1}{e_1} + \frac{A_1}{A_2}\left(\frac{1}{e_2} - 1\right)}$$

Table II

Section #	$\frac{1}{e_1}$	$\frac{A_1}{A_2}\left(\frac{1}{e_2} - 1\right)$	$\sigma A_2 T^4$	W
1	1.67	0.128	6.44	3.57 watts
2	1.67	0.148	6.44	3.54 watts
3	2.5	0.148	9.3	3.5 watts
4	1.67	0.131	3.85	2.1 watts

The total radiated power is almost 13 watts, which is much greater than the cooling power available. To reduce the power radiated by the baffle, two main options are open to us, viz. reducing e_1, or reducing e_2. The copper sections of the baffle can be polished, which may reduce e_1 to as low as 0.019.[6] The alumina portion (section 3) cannot have its emissivity reduced as readily. However, if the glass tube is aluminized, e_2 can be reduced to 0.018. Then the parameters in Table II become:

Table III

Section #	$\frac{1}{e_1}$	$\frac{A_1}{A_2}\left(\frac{1}{e_2} - 1\right)$	W
1	52.6	63.2	0.056 watts
2	52.6	72.5	0.052 watts
3	2.5	72.5	0.1 watts
4	52.6	64.4	0.033 watts

These changes will reduce the power radiated by the baffle by two orders of magnitude, and should permit the retina holder temperature to approach the desired temperature of 80°K.

4. Electrical Design

The design of the demountable camera tube was based on the desire to use, wherever possible, standard parts or standard designs. Consequently, the electrical subsystem consists of a standard GE Image Orthicon camera, Model TE-17, with appropriate modifications. Figure 6 shows a block diagram of the electrical subsystem, showing the use of the TE-17 for sweep, sync and video processor, as well as for focus current supply, etc. Functions not derived from the TE-17 were filament supply, pre/post amplifier, and target supplies.

a. Filament Supply

Due to the need to activate the cathode in the tube, and continually cycle it to atmospheric pressure and back when changing retinae, cathode emission is a continuing problem. The use of a separate supply provided the flexibility needed in this area. This supply has three operating modes, viz. Activate, Operate and Standby.

(1) Activate

In this mode, the filament supply is connected as shown in Figure 7. The activation schedule is also given.

(2) Operate

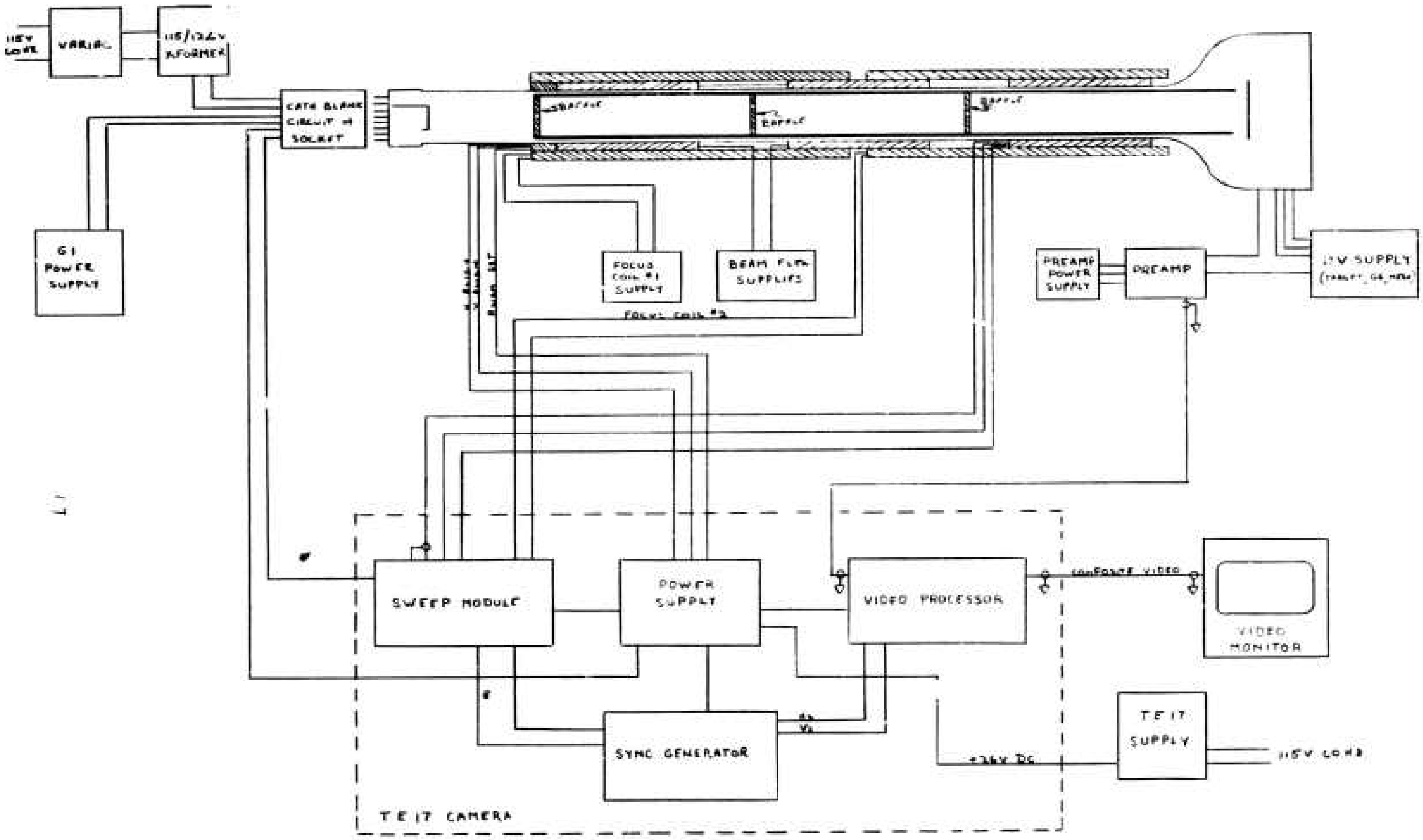
In this mode, G1 bias is supplied from an external supply and cathode current is monitored by a 1 mA full scale panel meter.

(3) Standby

In this mode, filament current is reduced to 0.3 amperes, while G1 is bias ~ -5 volts with respect to cathode, to prevent ionic poisoning of the cathode.

b. Target Supply

To avoid possible problems in the cathode blanking circuit and in maintaining isolation between cathode and filament, the cathode of this system is operated at system ground potential. The mesh is biased relative to the cathode to obtain the desired high primary beam velocity, and the target and G6 (collector) are biased relative to the mesh. Mesh voltage (V_{MK}) can be varied smoothly over the range 0-1000 volts, while target to mesh voltage



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2-PLACE DECIMALS ± 3-PLACE DECIMALS ± ANGLES ± FRACTIONS ± ALL SURF. ✓ MATERIAL—	SIGNATURES: 2 4 74	GENERAL ELECTRIC DEPT LOC
		BLOCK DIAGRAM OF ELECTRICAL SUBSYSTEM FOR DEMOUNTABLE CAMERA TUBE FIGURE 6
		SIZE C CODE IDENT NO.
		SCALE SHEET

2-Hour Bake at 350°C

Time (Minutes)	Heater Current	I_k
10	.4	0
10	.5	0
10	.6	0
3	.7	10-50 μA
2	.8	1 mA
3	.7	700 μA
2	.8	1.5 mA
3	.7	1 mA

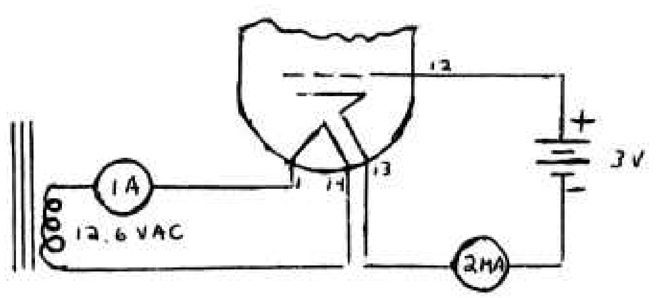


Figure 7. Circuit for Activating Cathodes and Activation Schedule

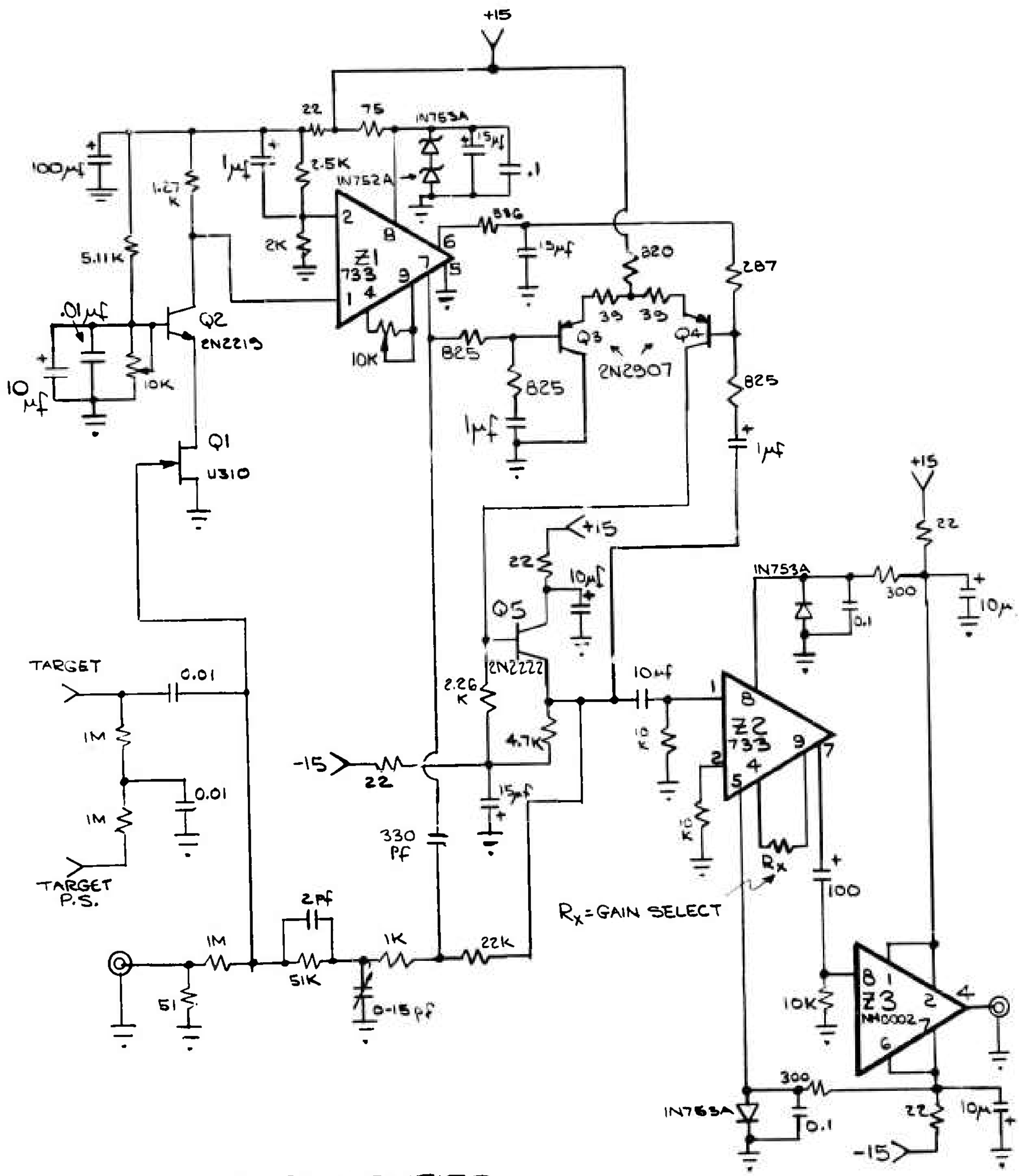
(V_{TM}) can be varied over the range -40V to +40V. The collector electrode (shown in Figure 4) collects secondary electrons from the mesh, and can be biased over the range 0 to +100 volts relative to the mesh. Current flow in each of these legs can be measured, using Keithley electrometers.

c. Pre-Amplifier

The pre-amplifier used in conjunction with the direct target readout retinae under discussion was a transimpedance amplifier having an input impedance of 4 ohms, a transimpedance of 750K ohms, a bandwidth (-3 dB) of 5.3 MHz with zero capacitance across the input, and an equivalent input noise current of $\leq$ 10 nA at full bandwidth (Cf. Figure 8). To determine the minimum detectable input signal current, a bar generator was used to create an artificial image of variable amplitude, which was fed into the pre-amplifier, then into the video processor and into the Conrac monitor. It was found that input signals were discernible on the monitor down to 5 to 10 nA. While this was judged entirely satisfactory for the intended application, it could be reduced even further if needed by using better blocking capacitors at the pre-amplifier input.

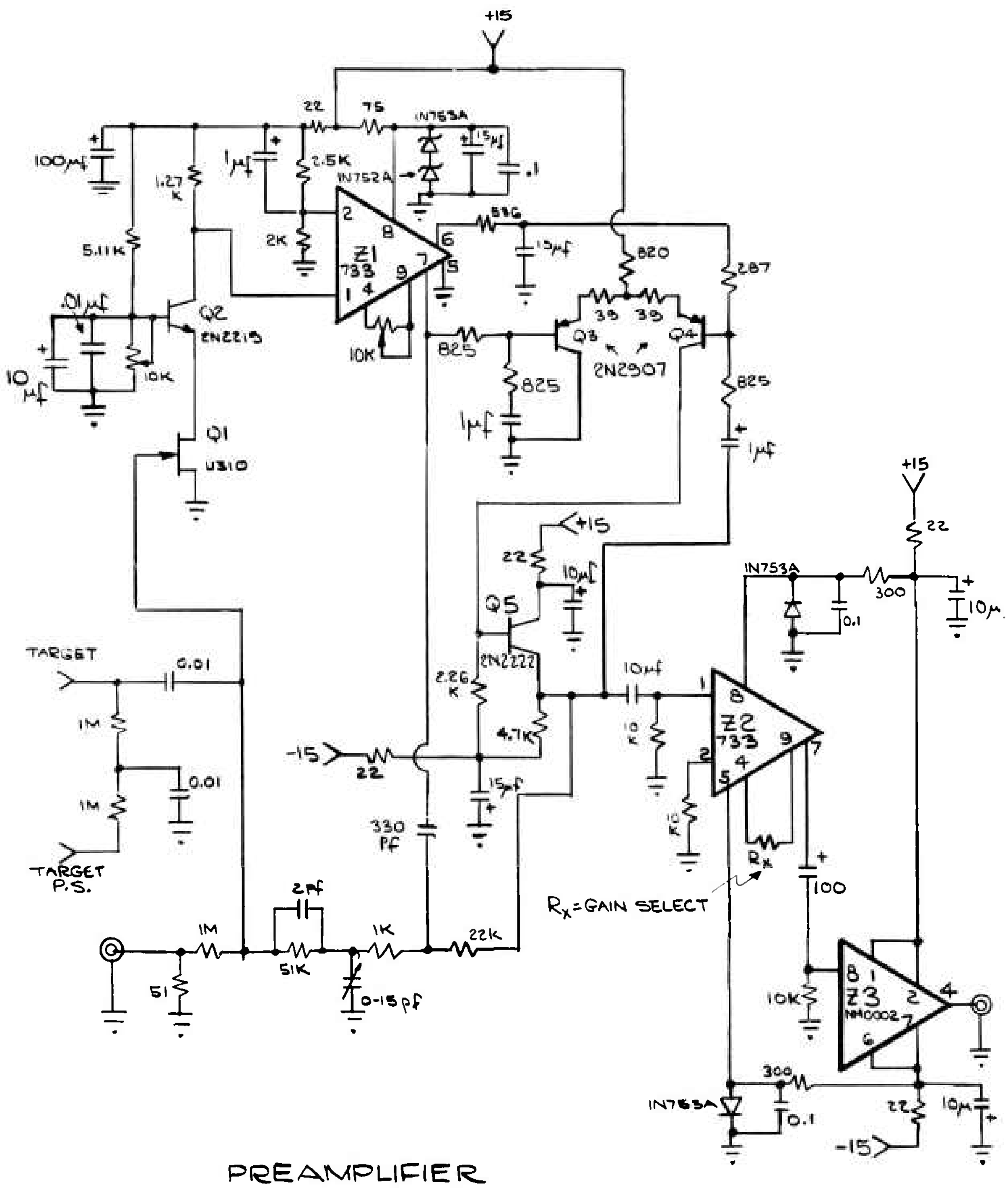
5. Retina Design

The particular material system selected for this program was palladium on P-type silicon. Palladium forms a stable silicide having a barrier height of 0.34 ev on P-silicon, giving a long wavelength cut-off of 3.65 μm. According to the criteria of Hall[7] and Dimmock,[8] this is the optimum spectral region in which to use infrared vidicons. The mask set used produced a 34 mm diameter array of 8 μm square diodes on 10 μm centers. Cuts were made in this pattern in a 0.5 μm thermal oxide grown on 2-inch wafers of P-type silicon of two different resistivities, 3 ohm-cm and 10 ohm-cm. Palladium of two different thicknesses (500 Å and 5000 Å) was deposited and sintered at 270°C for 5 minutes in 50:50 H_2,N_2. Unreacted palladium was then etchedoff without removing the Pd_2Si, leaving the desired diode pattern. Ohmic contact to the P-region consisted of an annular ring, 0.125 inch wide and 2 inches O.D. of sintered platinum of the side of the wafer opposite to the diode array. (The forward voltage drop calculated for this contact at 1 μA is 70 mev.) Figure 9 shows a photograph of a finished retina at X1 and X1000.



PREAMPLIFIER

FIGURE 8



PREAMPLIFIER

FIGURE 8

Figure 9. Photographs of Retina at X1 and X1000 Magnification

a. Diode Isolation

P-N junction diode array vidicon targets suffer from problems of surface inversion, which shorts adjacent diodes. This problem will not bother cooled Schottky diode vidicon targets for two reasons:

(1) There are no means for generating minority carriers in the bulk to re-supply an inverted surface. Thermal generation is minimal, especially at the target operating temperature of $77^{\circ}K$. Optical generation of minority carriers requires photons of $\lambda < 1.1\ \mu m$, which are filtered out by means of a silicon pre-filter.

(2) In the case of adjacent metal islands sitting at different potentials, any minority carriers initially present at the surface will flow to the appropriate island, but the other island cannot serve as a source of additional minority carriers, since its barrier to minority carriers is higher than its barrier to majority carriers.

As a result of this freedom from surface inversion, and in view of the resistance of a high beam velocity tube to degradation of beam landing characteristics by oxide charging, it appears that these retinae will not require a resistive sea. In view of the lack of information on the properties of resistive sea at $77^{\circ}K$, this development is a happy one.

6. Electron Optics

As stated previously, the electron guns used in this demountable camera tube were the same as those employed in the General Electric Company Z7966 3-inch Image Orthicon camera tube. Magnetic deflection and focusing were used. The only unique problem encountered in electron optics arose due to the need to baffle the retina from thermal radiation from the hot cathode. The baffle employed was based on a design employed by Dr. R. Redington of GE Corporate Research and Development Department, and by H. Sippach of the Imaging Systems Operation of the General Electric Company, and can be seen in Figure 5. It consists of three sections: Sections 1 and 2 consist of a 12-inch polished copper tube, 1.567 inches in inside diameter with 0.032 inch wall thickness, having three copper discs situated on the axis of the tube. The first and third disc have an aperture, 0.375 inches in diameter, on axis. The second has a similar hole, 0.5 inches off axis. The electron beam can be caused to thread through these three apertures by applying dc focus

and deflection fields of the proper magnitude and sign. Thus, aperture number three becomes an effective cathode, but without the thermal radiation associated with the actual cathode. Section 3 is a 7.5 inch long ceramic cylinder, 1.630 inches O.D., 1.380 inches I.D., metallized on the inside in two sections. The section closest to the copper tube is electrically connected to the copper tube, and operated at G4 potential. The section closest to the retina serves as a collector for secondaries from the mesh, and operates at G6 potential. (G6 must be at least +20 volts above cathode, or it cuts off the beam.) Section 3 is ceramic rather than copper to minimize eddy current losses, since this is where the x-y deflection is done for beam scanning.

a. Retina Assembly

The retina assembly, shown in Figure 4, consists of four parts, viz. a filter, the retina, the grid mesh, and a cylindrical collector electrode (not shown in Figure 4).

(1) Filter

Because of the high sensitivity of metal-silicon Schottky barrier diodes to silicon band edge radiation, it is necessary to block room light from hitting the retina. A long pass filter (such as a silicon wafer) or a band pass filter can be used for this purpose.

(2) Retina

The retinae used are described above, and were contacted by a copper disc pressed against the Pt ohmic contact. This pair was sandwiched by nylon discs to provide electrical isolation, and cooled radially from the copper retina assembly holder.

(3) Mesh

The electron beam lands on the retina with a relatively high energy (~ 300 volts). Secondaries will thus be generated, charging the retina surface positive. These secondaries must be collected by a mesh and prevented from falling back on the target and discharging it. This is done by a conducting mesh, situated immediately above (on the beam side) of the retina surface. This mesh has high transparency to the incident beam, should be spaced 0.002" to 0.005" (or less) from the retina surface, and be electrically isolated from this

surface over the temperature range to which the retina will be subjected. 750 L.P.I. electroformed mesh is preferred, but other sizes can be used.

(4) <u>Cylindrical Collector (G6)</u>

Secondaries emitted by the mesh must also be collected. This is done by a cylindrical electrode 1.380" in diameter and 3" long located on the inside of the ceramic section of the baffle. This collector, as well as the mesh and the target, must be electrically isolated from each other and the rest of the tube, and available at the window end of the tube.

7. <u>Optics</u>

The main problems encountered in the design and operation of this tube in the area of optics dealt with the unvignetted aperture seen by the retina, and the window material. It was decided to evacuate the test chamber between the retina and the window, and also to position the cooling finger in the same portion of the test chamber, to avoid possible problems with electron optics. Thus, the retina is situated well back from the window. By designing the retina holder assembly to cold finger joint with care, an unvignetted aperture F number of F/5 was obtained. This was felt to be adequate for the intended application.

The window material used was water free quartz, 3.75 inches in diameter and 3/16 inches thick. This material has a transmittance $> 90\%$ at 3 μm, and an absorptance $< 5\%$ at 2.7 μm.

SUMMARY AND CONCLUSIONS

The demountable camera tube system described above has been built and tested, and is currently being used in on-going studies of infrared imaging using metal-silicon Schottky barrier infrared vidicon retinae. The tube can be operated in the high beam velocity mode (either positive or negative variation[4]), or in the low beam velocity mode. An electron beam of variable primary energy and beam current of up to 200 nA can be raster scanned at standard TV rates across cooled retina ($T \approx 90^{o}K$) which is protected by a cooled baffle from radiation from the hot cathode. Direct target readout is employed, using a pre-amplifier having an equivalent input noise current of better than 10 nA through full video bandwidth. The system can be cycled repeatedly between atmospheric pressure and high vacuum ($P \approx 3 \times 10^{-8}$ Torr), using the same thermionic cathode. It appears that the use of certain simple precautions permit 5 to 10 cycles before cathode replacement is necessary.

The retina structure which was developed under this contract and which is currently under continuing study consists of an active region 34 mm in diameter of 8 μm square diodes on 10 μm centers. It shows a long wavelength cut-off of 3.65 μm, is self-reticulated, and free from blooming arising from surface inversion. Excellent resolution and lag characteristics are anticipated.

In conclusion, the demountable camera tube described herein provides an excellent experimental tool for studying infrared vidicons, especially high beam velocity mode tubes.

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